No. 1 ESS ADF:

Teletypewriter Stations and Transmission Facilities

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A solid-state electronic station controller, small enough to be housed within Model 33, 35 and 37 teletypewriters, administers station on-line procedures. To realize automatic message reception and transmission at the station, the controller samples all traffic exchanged between the line and the station teletypewriter, detects message-and device-control characters and generates and detects station-identity codes. In addition, the controller monitors the status of the station teletypewriter and provides appropriate alarms which are displayed on an attendant unit.

Stations are linked to the No. 1 ESS ADF office via the Bell System's private line telegraph network. New ac and dc data sets have been developed to accommodate speeds up to 300 bauds with lower distortion and crosstalk generation than previously attainable with former transmission apparatus.

I. INTRODUCTION

1.1 *Facilities*

With the advent of the No. 1 Electronic Switching System, Arranged with Data Features (No. 1 ESS ADF), the art of store-and-forward switching has been significantly advanced in the areas of reliability, capacity and feature capability. Interconnection between the newly designed stations and the message switcher is provided by existing Bell System and Independent Company private-line telegraph facilities. Only minor modification was required to modernize these facilities for use with the higher data rates of No. 1 ESS ADF.

The private-line telegraph system contains a large number of centrally located offices which provide both transmission and maintenance facilities. These locations are interconnected by a variety of carrier systems, utilizing channels derived from frequency division of voice channels shared with other subscribers. This sharing of facilities pro-

vides the subscriber with significant savings. At each location, the data signals of a channel are demodulated to baseband. Any number of individual baseband "legs" can be combined by an interconnecting circuit called a "hub." The basic function of a hub is to permit all outgoing legs to transmit what has been received on an incoming leg. As shown in Fig. 1, hubs can be interconnected to permit multistation arrangements or a hub may simply be used to interconnect two carrier channels, or to connect a final channel to the local loop of a station. In this way, hubs are well suited to the formation of party lines and broadcast systems.

Each hub has one additional leg, providing alarm, monitor and test circuits at the local service board. This expedites trouble locating and at times even makes it possible to anticipate service failures by the early detection of deteriorating transmission margins. Rerouting of circuits is often possible, ensuring prompt re-establishment of service. Due to these features, the private-line telegraph system has achieved high reliability and continuity of service. Over the years, a large network of shared hub-to-hub links, readily capable of meeting the growing needs of subscribers, has been established throughout the United States.

At times, the most efficient trunk utilization between two stations may require quite a circuitous route, i.e., many hub-to-hub links may be involved. To compensate for the accumulating distortion of the

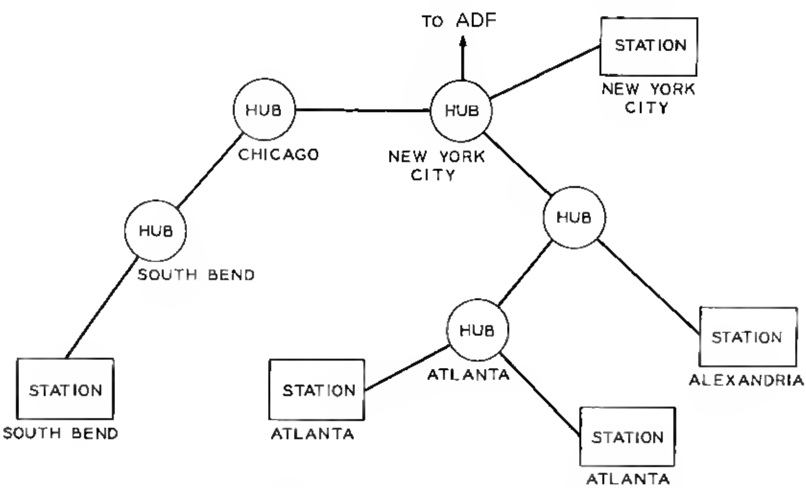

Fig. 1—Typical network illustrating use of hubs for a multistation arrangement.

many modulations and demodulations of the data signals, data-stream regenerators may be added at appropriate bub points. These regenerators restrict the network to a limited number of speeds and code structures.[1] The No. 1 ESS ADF code structures are compatible with such restrictions.

Although the system presently operates at a maximum of 150 bauds, new data sets have been developed for this system to provide data transmission at speeds up to 300 hauds between the huh and the station, anticipating the need for future increases in speed. At the same time these new data sets produce considerahly less electrical noise on the loops than previous arrangements which operate at voltages compatible with vacuum-tube circuits.[2]

One office, near the No. 1 ESS ADF office, is designated as the controlling serving test center. Special data sets have heen developed to provide a lower-cost arrangement for the link between this center and the No. 1 ESS ADF office, taking advantage of the fact that this link is expected never to exceed one mile.

1.2 *Stations*

Both half-duplex and full-duplex teletypewriter stations have heen developed for this system. Half-duplex stations may send and receive message traffic sequentially, but not simultaneously, while full-duplex stations may send and receive messages simultaneously. Messages are transmitted from a station from punched paper tape and are received at a station as printed-page copy and/or punched-paper tape. The stations described in this paper use the USA Standard Code for Information Interchange (ASCII)[3] and operate at either 100 or 150 words per minute.*

1.2.1 *Station Configuration*

The functional form of the half-duplex station is shown in Fig. 2. The station controller conducts the control dialogue with the No. 1 ESS ADF processor (ADF)[4], directs the flow of data within the station and controls the operation of the teletypewriter. The teletypewriter sends and receives all message traffic and the attendant unit, consisting of lamps and keys, permits the station attendant to initiate actions at the station and observe the status of the station.

The attendant unit and controller are pbysically mounted within the

* Presently all stations operate at either 100 or 150 words per minute and use ASCII. However, ADF is arranged to accommodate stations that operate at 60, 75 and 100 words per minute and use the Baudot code.

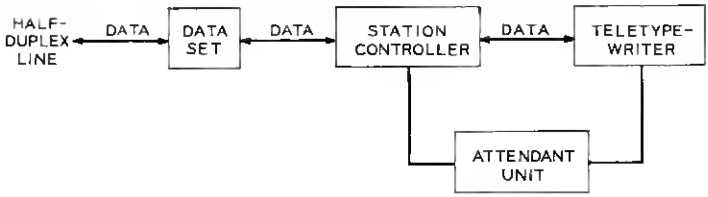

Fig. 2—Functional form of half-duplex station.

teletypewriter. Figure 3, for example, shows the front view of a half-duplex station equipped with a Model 33 automatic send-receive (ASR) and an optional Model 33 receive-only (RO) teletypewriter; this station many send and receive message traffic. The attendant unit is mounted to the right of the keyboard of the ASR. The RO is an optional secondary receiver which allows messages or any portion of them to be received at either or both the ASR or RO, thus permitting separation of received traffic into message categories. All message traffic originated at the station is printed as local copy on the ASR. In Fig. 4 the station controller is shown mounted in the pedestal of a Model 33 ASR.

The functional form of the full-duplex station is similar to the half-duplex station and is shown in Fig. 5. The station controller performs all of the functions mentioned previously but in addition permits the station to send and receive messages simultaneously. Because of this simultaneous operation, two teletypewriters (one send and one receive) are provided, whereas in the half-duplex station only one teletypewriter (send-receive) is necessary.

A typical send-receive full-duplex station equipped with Model 35 teletypewriters is shown in Fig. 6. The station controller is physically mounted in the ASR along with the send attendant unit. The RO has the receive attendant unit mounted in it and is shown equipped with an optional secondary receiver, a receive-only typing-reperforator (ROTR). A received message or any portion of it can be delivered to either or both the RO or ROTR while the local copy of traffic originated at the station is printed on the ASR.

1.2.2 *Controller*

The functional form of the half-duplex station controller is shown in Fig. 7. Data may be received from either of two sources, the half-duplex line or the teletypewriter, and since the station is half duplex,

these sources are never active simultaneously. The data is passed to the character storage, detection and generation circuits where each character received by the station is temporarily stored. Those characters which require some action on the part of the station are detected and the resulting information is passed to the logic circuits for processing. Suppose, for example, ADF is "polling" the station, i.e., asking the question "Do you have traffic to send?" This is part of the control dialogue and is accomplished by ADF sending a prescribed character sequence to the station. The characters are detected in turn by the controller detection circuits and an appropriate response is determined by the logic circuits based on the information available from the attendant unit and teletypewriter. With the response determined, the response character is generated and passed to the half-duplex line.

In addition to the detection and generation of control characters,

Fig. 3—Half-duplex station equipped with Model 33 teletypewriters.

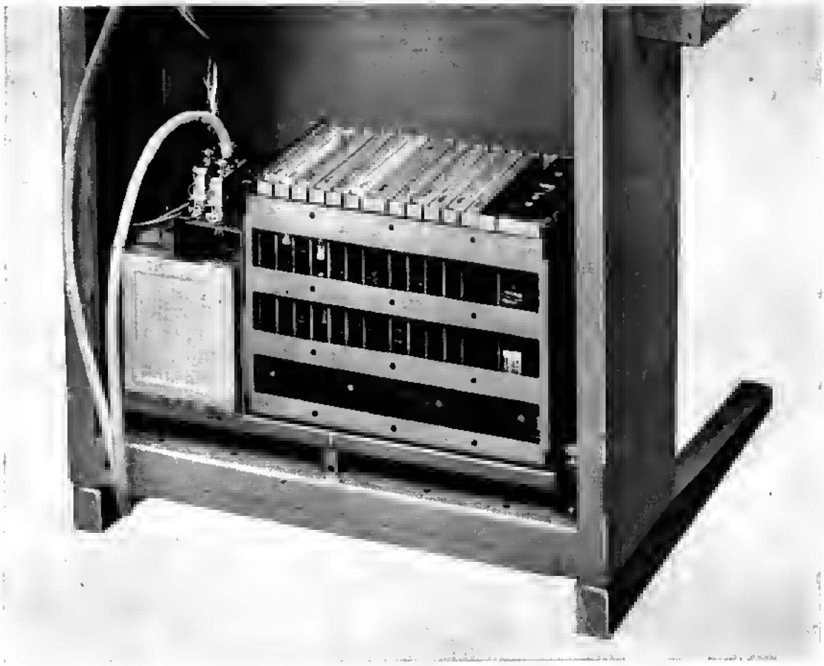

Fig. 4—Half-duplex station controller mounted in pedestal of Model 33 ASR teletypewriter.

the controller must also direct message traffic within the station. Consider, for example, a message at ADF whicb is intended for delivery to the station. ADF "selects" this station as a receiver using another prescribed control sequence and tben delivers the message to the station. At the station, the logic directs this message data from the half-duplex line, tbrough storage, to the teletypewriter. A more complete discussion of controller operation, including these functions, is presented in Section III.

The full-duplex station controller can be described in terms similar to those above except, as noted earlier, the controller must handle both message transmission and reception simultaneously. This means that while some of the functional blocks of the half-duplex controller are provided in duplicate in the full-duplex controller, the logical operation is similar.

1.2.3 *Attendant Unit*

Tbe attendant unit is an assembly of lamps and keys which displays the status of tbe station and permits the station attendant to

control the operation of the station. By means of operating these keys, an attendant may, for example, make a request to send a message. The lamps indicate such states as selected to send, selected to receive, alarm conditions, etc.

1.2.4 *Teletypewriters*

Teletypewriters of the Model 33, 35 and 37 product lines of the Teletype Corporation were adapted for use in the stations. In all, eight different types of teletypewriters are available: two Model 33s, the ASR and RO; three Model 35s, the ASR, RO and ROTR; and three Model 37s, the ASR, RO and ROTR. The Model 33 and 35 teletypewriters are shown in Figs. 3 and 6, respectively. The Model 37 teletypewriters are shown in Figs. 8, 9 and 10. The Model 33 and 35 teletypewriters operate at 100 words per minute and the Model 37s at 150 words per minute and all use ASCII. The Model 33s are intended for limited usage while the Model 35s and 37s may be used continuously. Selection of the type of teletypewriter for use at a station depends on such items as station usage, machine features, cost objectives, etc.

II. TERMINATION TRANSMISSION LINKS

2.1 *Station Links*

ADF has a direct and permanently connected link to every station in its system. For the sake of economy, the channelized trunk routes between hubbing locations can be shared with other subscribers of the private-line telegraph system, and stations on multipoint lines of the No. 1 ESS ADF system can share a single channel, being connected

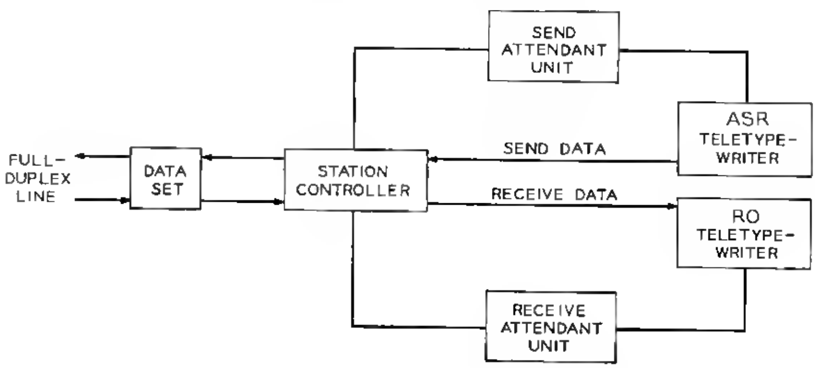

Fig. 5—Functional form of full-duplex station.

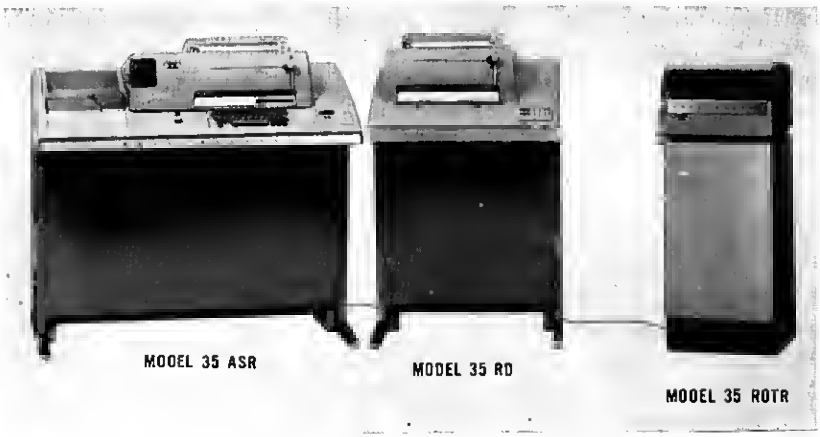

Fig. 6—Full-duplex station equipped with Model 35 teletypewriters.

to ADF on a "party line" basis. In contrast the last transmission link, between the station and its nearest telegraph office, is always individual to the station.

As previously mentioned, new end-link data sets were designed. The basic objectives of these new designs were: higher-speed capabilities than heretofore available for end links, less electric interference into other circuits on the same cable than some existing equipment, and simplicity of equipment to keep costs comparable to previous services.

Two new types of data sets for transmission links were introduced: one uses ac (voice frequency) transmission, the other polar dc.

2.1.1 *DC Data Set*

One new type of data set developed for the system, coded 109, uses polar dc transmission combining reliability of operation with low cost. The limitations of this method are the need for metallic cable pairs and the restricted range of operation, namely, 2500 ohm loop resistance, ranging between 6 and 15 miles depending on the gauge of wire used. Yet, because of the strategic distribution of service locations, the probabilities are high that a sizable portion of the stations of any system can be served by these dc facilities.

The functional form of the data set 109 is shown in Fig. 11. It contains a transmitter which acts as a low-impedance voltage source. The data set applies 4 volts between the wires of tbe line for a mark, and

12 volts of opposite polarity for a space. The data set at the other end of the line is similar, but is connected with opposite polarity to the metallic conductors. Thus, the voltage around the loop, including both data sets, is 8 volts for marking signals generated at both ends. If either end sends a spacing signal, the voltage around the loop changes to 8 volts in the opposite sense. Resistance padding is used to keep the total of line-plus-pad resistance constant. Thus, the loop current for two marking data sets is about 3 mA, while the loop current for one marking and one spacing data set results in current flow of 3 mA in the opposite direction around the loop.

Each set contains a pair of monitor resistors, one inserted in the "tip" and one in the "ring" leg of the transmission line. Under favorable conditions, the polarity of the voltage drop across either resistor indicates whether both data sets are marking, (i.e., current flowing in one direction) or whether one set is marking and the other spacing (current flowing in the opposite direction). In practice, longitudinal currents may flow along the line due to a ground potential difference between the two ends. As this potential difference may exceed the source voltage of the transmitters, the current in either monitor resistor may drop to zero or even reverse direction. On the other hand, by checking the voltage drop in both monitor resistances simultaneously with a differential circuit, the voltage drop due to the loop current can be found independently of the longitudinal current. This information then yields the data condition of the data sets.

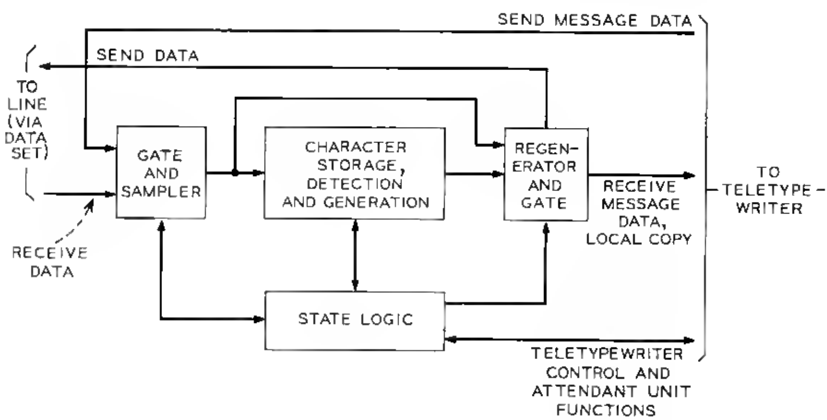

Fig. 7—Functional form of half-duplex station controller.

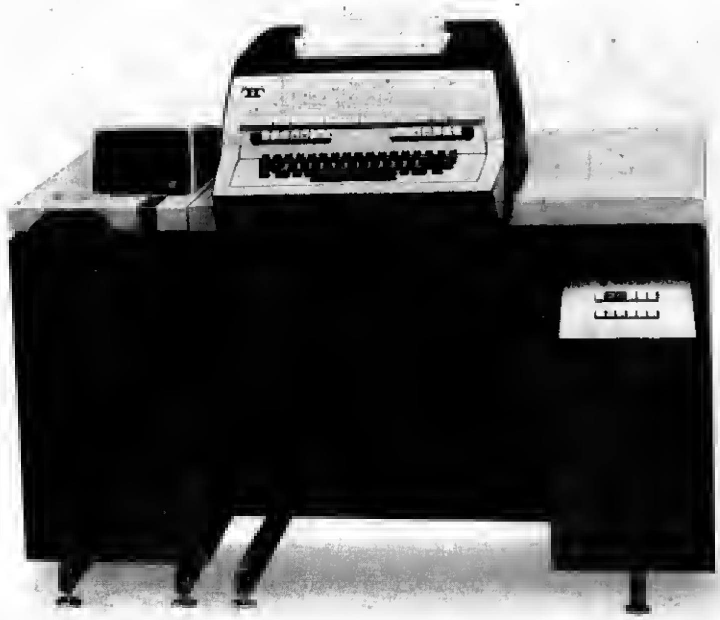

Fig. 8—Model 37 ASR teletypewriter.

Other circuitry detects loss-of-loop current, a condition which indicates a failure of the local portion of the transmission facilities. There is also provision to suppress "copy" of the transmitted signal in the receive lead of the same set. The entire circuit is contained on a single printed circuit board for easy installation at the station and in the telegraph office.

Extensive tests of data set 109 have yielded very satisfactory results. The set operates with less than 5 percent peak distortion on lines up to 2500 ohm loop resistance and under 1 μF capacitance at 150 bauds. It will work with proportional increases in distortion up to 300 bauds. The set can tolerate up to 20 volts dc and ac ground potential difference. The electrical interference generated by the set is sufficiently low not to adversely affect other circuits.

The data set 109 just described is restricted to half-duplex operation; however, a full-duplex version of this data set, operating over 2-wire

lines, is now in preparation and will be applicable to the No. 1 ESS ADF system.

2.1.2 *AC Data Set*

Whenever full-duplex service is required, or whenever the distance between the last hubbing location and the station is such that the limits for dc transmission would be exceeded, ac (voice frequency) transmission is used. A new type of data set was designed to permit operation at the speeds of the No. 1 ESS ADF system.

Fig. 9—Model 37 RO teletypewriter.

Fig. 10—Model 37 ROTR.

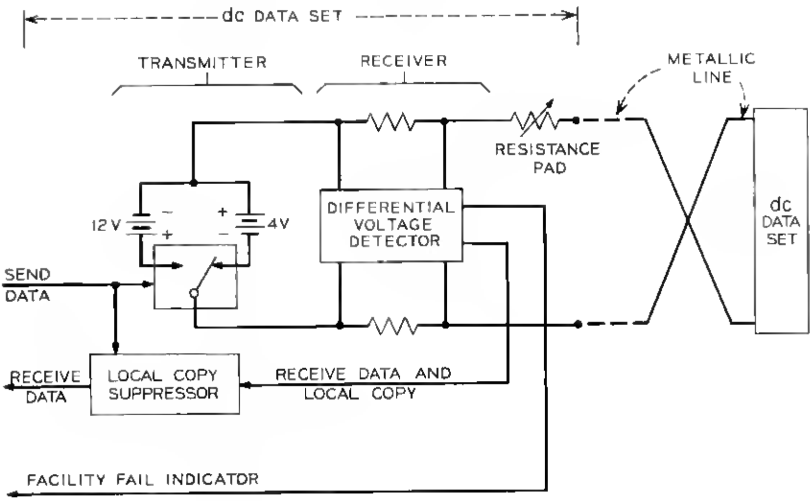

Fig. 11—Functional form of dc data set.

This data set, coded 108, contains a frequency-shift modulator, generating 2125 Hz ±100 Hz and 1170 Hz ±100 Hz at the station and at the hub, respectively. These frequencies are used in Teletypewriter Exchange (TWX) and DATA-PHONE® services and have been maintained for private-line telegrapb end links, so that the test facilities in central offices can be shared. Receive circuitry employs conventional FSK demodulating techniques. The send-and-receive frequencies of the station set match tbe receive-and-send frequencies of the central-office set. The data-set circuitry is contained on a single printed circuit board, which is physically interchangeable with data set 109. Data set 108 is shown in Fig. 12. The peak distortion of data set 10S at 150 bauds is less than 10 percent over transmission lines with up to 30 dB end-to-end loss at a signal-to-noise ratio of 10 dB. With a proportional increase in distortion, it will work up to 300 bauds.

2.1.3 *High-Voltage Circuits*

The data sets described above have input and output circuits in the typical low-voltage range of transistor circuits: under 24 volts. At tbe hubbing location, data sets 108 and 109 must connect to the existing high-voltage hub circuits which were designed for vacuum-tube circuits with a +130 volt plate supply. An auxiliary circuit has been designed to provide the proper voltage conversion between hub and data set circuits. As data sets 108 and 109 have the same characteristics at

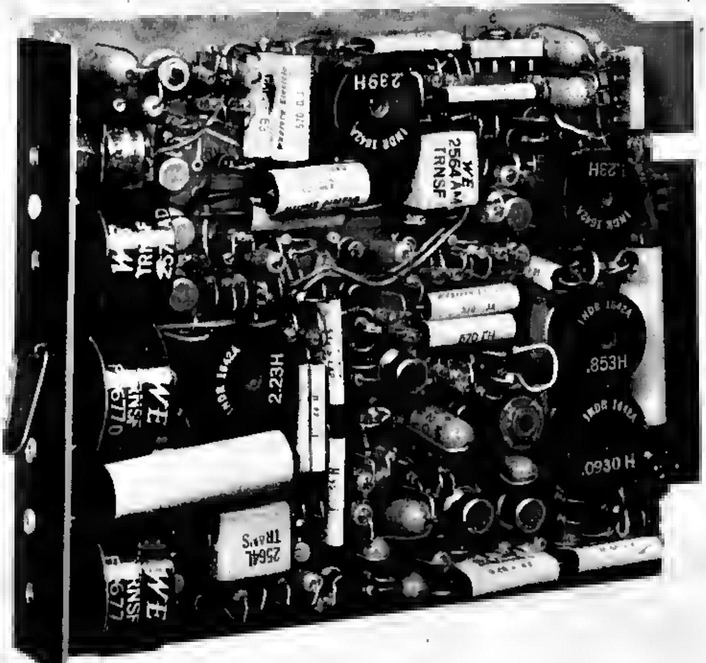

Fig. 12—Data Set 108 type.

tbeir baseband interface, the same auxiliary circuit is used for either set.

This circuit, coded data auxiliary set 811C, contains multistage conversion circuits to effect the necessary step-up and step-down in voltage. The auxiliary set also contains the directional control for use at half-duplex hubs to prevent copy received from its data set from being sent back to the same data set by the hub.

2.2 *Office Link*

The ADF office is always located close to the first hubbing location which is its serving transmission center, usually in the same building. It was therefore possible to utilize a dc transmission scheme without ground potential compensation. To accommodate full-duplex stations,

the transmission on this link has to be full-duplex also. This is achieved by the use of 4-wire facilities between the serving office and the ADF office, keeping data-set circuits as simple as possible.

At the serving office a single circuit board, containing the dc data-set circuit as well as the low-voltage to high-voltage conversion circuits, is used. At the ADF office only a low-voltage interface is needed and the conversion circuits are not required. Therefore, the dc data set may be mounted on one of the smaller No. 1 ESS circuit boards which permits 256 data sets to be accommodated on a single frame.[5,6] Facility interruption is indicated at both ends of the link by detection of the loss of dc line current.

III. STATION OPERATION

3.1 *Character Format*

As in most teletypewriter systems, asynchronous character timing is employed. In this mode of operation, referred to as start-stop, a fixed-timing pattern is used for each group of bits representing a character. Each group is preceded by a start element which serves to

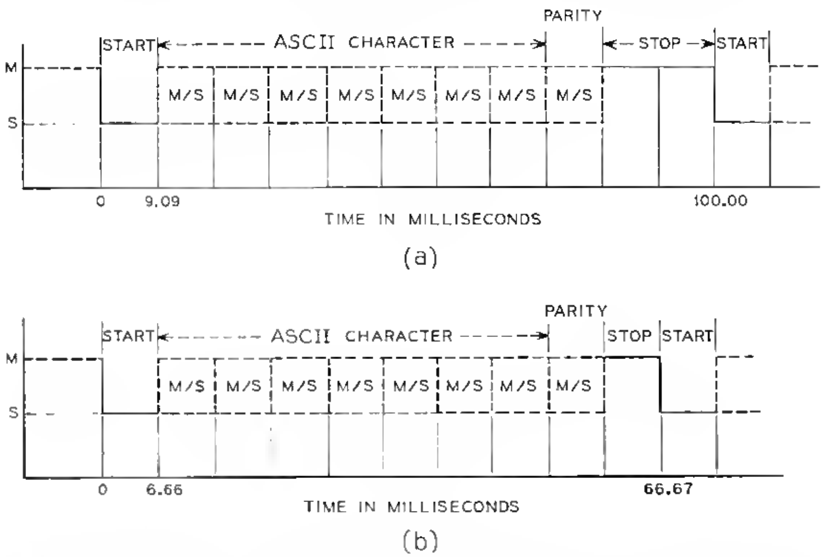

Fig. 13—Character format of teletypewriter signals. (a) Format at 100 words per minute. (b) Format at 150 words per minute. M = mark, S = space, M/S = mark or space.

indicate when a fixed pattern is to start. The character format for 100 words per minute (10 characters per second) and 150 words per minute (15 characters per second) is shown in Fig. 13. Each character consists of a spacing start element, a seven-bit ASCII character, a parity bit, and two (100 words per minute) or one (150 words per minute) marking-stop element(s). The parity bit is chosen (mark or space) so that the eight-bit character consisting of the ASCII character and the parity bit, contains an even number of marking bits.

The station controller is automatically sequenced through message handling operations by selected control characters, a subset of the

Table I—USA Standard Code for Information Interchange (ASCII, USAS x3.4—1967)

Bit Value				$b_7 \rightarrow$ $b_6 \rightarrow$ $b_5 \rightarrow$	0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
b_4 ↓	b_3 ↓	b_2 ↓	b_1 ↓	Column → Row ↓	0	1	2	3	4	5	6	7
0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	2	STX	DC2	"	2	B	R	b	r
0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
1	0	0	0	8	BS	CAN	(	8	H	X	h	x
1	0	0	1	9	HT	EM	)	9	I	Y	i	y
1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
1	0	1	1	11	VT	ESC	+	;	K	[	k	{
1	1	0	0	12	FF	FS	,	<	L	\	l	¦
1	1	0	1	13	CR	GS	–	=	M	]	m	}
1	1	1	0	14	SO	RS	.	>	N	^	n	~
1	1	1	1	15	SI	US	/	?	O	_	o	DEL

ASCII alphabet. Some of these characters are part of the normal message format and some are transmitted out of message context, for line-control purposes. The complete ASCII character set is given in Table I. Characters listed under columns 0 and 1 in the table are defined to be control characters.

3.2 *Sending from the Station*

Messages for transmission from the station are prepared on paper tape using the teletypewriter keyboard and tape punch. Messages must possess the following format:

	DS		*S*		*ED*	
···	*EO*	Heading	*T*	Message Text	*TE*	···
	LH		*X*		*XL*	

The message heading, separated from the message text by the control character STX (Start of Text), includes the addresses of those stations that are to receive the message text. The control characters SOH (Start of Heading) and ETX (End of Text), denoting the beginning and end of the message, together with STX, are detected by ADF and the station controller to initiate message handling sequences. To provide a tape leader that facilitates introduction of the prepared tape into the teletypewriter tape reader, a number of DEL (Delete) characters are punched in the tape prior to SOH. Several messages may be sent by the station during a single transmission. In this case, additional messages with the prescribed format are prepared on the same tape with DEL characters used to physically separate the messages. An EOT (End of Transmission) control character is punched in the tape following the ETX of last message to denote termination of the transmission.*

To initiate the sending sequence, the tape containing the prepared message is inserted into the tape reader, and the tape reader is started by the controller when a key (BID) on the station attendant set is operated. Alternatively, at stations equipped with Model 35 or 37 teletypewriters, tape may be fed directly into the tape reader from the punch and the reader started automatically when the EOT character is punched in the tape. In this case, a differential counter in the station controller is incremented each time an EOT is punched during

* Since certain control characters automatically initiate message control sequences, both at ADF and at the station, they may never appear in the message heading or text. These control characters are SOH, STX, ETX, EOT, ENQ (Enquiry) and DLE (Data Link Escape).

message preparation, and decremented each time an EOT is detected by the controller during actual transmission to the line. The advantages of this feature will be noted in subsequent sections.

The controller discards the DEL characters and stops the tape reader upon detection of the SOH character. At this point the controller logic is now conditioned to generate and transmit control characters indicating that the station has traffic to send upon interrogation by ADF.

3.2.1 *Polling*

ADF periodically interrogates each station on a line in order to determine if the station sender has traffic to originate and if the station receiver is ready to receive traffic. The polling cycle begins when ADF transmits the control character DLE (Data Link Escape). This character causes all station controllers on the line to assume the polling state. Programmable character detection circuits in the station controller permit each station on the line to be assigned a unique station-polling code which is selected from the set of ASCII printing characters.* Upon receipt of the appropriate polling code from ADF, the controller generates and transmits a 1- or 2-character sequence, depending on the status of the station. The possible responses and their significance are as follows:

CAN (Cancel): this character indicates that the station has no traffic to send, but is ready to receive.

NAK (Negative Acknowledge): NAK is transmitted if the station has no traffic to send and is not ready to receive. The station is defined as "not ready" for any of the following reasons:

(*i*) The receiving† teletypewriter does not have sufficient paper (or tape, in the case of an ROTR).

(*ii*) The receiving teletypewriter is in the process of feeding form‡ or tape, a process that may have been initiated as the station returned to the idle state after receiving a previous message.

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* Characters included in Columns 2 through 7 of the ASCII code, except characters SP and DEL, are printing characters. The characters P, R, W, X and + have special significance in the operation of the controller and therefore are not usable as station-polling codes.

† Most of the operations described are common to both full- and half-duplex stations; where operations are not the same in both cases, the differences will be noted. When reference is made to the sending or receiving teletypewriter it should be understood that in the case of a send-receive half-duplex station, these teletypewriters are one and the same.

‡ ASR and RO teletypewriters may be equipped with either a typing unit that uses paper on rolls or one that uses fan-folded paper forms.

(*iii*) The station has been put out-of-service using a key on the attendant set.

R ACK (Regular Acknowledge): this two-character sequence is generated if the station has regular (nonpriority) traffic to send and is ready to receive.

P ACK (Priority Acknowledge): the meaning of this sequence is similar to that for R ACK, except the available traffic in this case is of priority level. The priority level is assigned by the station attendant using a key on the attendant unit.

R NAK (Regular Negative Acknowledge): these characters indicate regular traffic available but the receiving teletypewriter is not ready to receive.

P NAK (Priority Negative Acknowledge): similar to R NAK, except that traffic is of priority level.

On half-duplex lines, if none of the stations indicate traffic available, ADF can return all stations to idle by transmitting a control character. If all stations on a full-duplex line respond "no traffic available," ADF transmits a control character which causes the sending logic of the controller to assume the "cocked" state. A programmable character-generation circuit in the controller permits each station on a line to be assigned a unique station-identity code, selected from the set of printing ASCII characters, with the same exceptions as noted for the station-polling code. When the full-duplex controller is in the cocked state, it will automatically generate and transmit this code when an SOH character is detected from the station's tape reader. ADF detects the activity on the line and interprets this as a polling request. Ordinarily, ADF would not discover that a station on the line had traffic to send until the next periodic polling cycle. Polling subtracts from the time available to ADF for message delivery, therefore, the cocking feature increases the efficiency of full-duplex lines. The efficiencies of the cocking feature cannot be realized on half-duplex lines since interference would result at the half-duplex hub if a station attempted to send at the same time ADF was sending.

On both half- and full-duplex lines, when a station indicates traffic available, ADF will normally proceed to the message pick-up operation, as described in the next section.

3.2.2 *Message Pick-up by ADF*

The programmable character-detection circuits in the station controller also permit each station on the line to be assigned a different call-enquiry code chosen from the ASCII printing characters, with the

same exceptions as noted for the station-polling code. After identifying those stations with traffic available during the polling cycle, ADF begins the traffic pick-up sequence by transmitting the control character ENQ (Enquiry) followed by the call-enquiry code of the station to be selected as a sender. When the controller detects this, it automatically generates and transmits one of two possible control characters. If SOH has been detected from tape, as described in Section 3.2.1, the controller is in the traffic-available state and will regenerate and transmit SOH, causing the station to be selected as a sender and a lamp (TRAN) to be lighted on the attendant unit of the sending teletypewriter. However, if the traffic availahle state bas been cancelled, by removing the tape from the tape reader for example, the controller responds with the control character NAK. If traffic is still available, i.e., the station responds with SOH, ADF transmits appropriate control characters causing the controller's data-gating logic to be conditioned to pass data received from the line to the typing unit of the sending teletypewriter. ADF may now transmit an originating message number for message identification as well as the time and date. At this point it is necessary to differentiate between half- and full-duplex operation.

On a half-duplex line, traffic can originate from only one source at any given time, either from ADF or from a sending station. This being the case, in addition to messages being forwarded by ADF, direct station-to-station communication or intra-line delivery under control of ADF is permitted. On a full-duplex line, however, botb a station and ADF may originate traffic simultaneously; therefore, to prevent interference, messages are handled on an interline basis only, i.e. all messages are stored and forwarded hy ADF. Tbe remainder of the description of messagc pick-up will be divided into two parts. Half-duplex operation will be discussed first.

3.2.2.1 *Half-duplex.* After transmitting the time, date and message number, ADF sends tbe go-abead control cbaracter STX. The controller detects STX and starts the station tape reader. The controller's data-gating logic applies the output of the tape reader to the station data set for transmission to the line. The controller also unhlinds the station printer so that local copy of the message is obtained. The controller monitors the transmission and stops tbe tape reader when STX, the control character tbat follows the message heading, is detected. Stopping the reader at this point in the sequence provides an opportunity for ADF to determine if any stations on the same line as tbe sending station are designated as addressees of the message. If this is the case, ADF will call in these stations, i.e., select tbese stations

as receivers, (see Section 3.3.1) provided of course they have indicated that they were ready to receive during a previous polling cycle. ADF then restarts the sending station's tape reader and the message text is transmitted. Upon detection of ETX, the control character denoting the end of the message, the controller again stops the tape reader. The called-in intraline stations receive the message directly from the sending station, and ADF stores the message for future delivery to the interline addressees. ADF "roll-calls" (see Section 3.3.2) all called-in receive stations to determine if they have received the message properly and then unselects them as receivers. ADF again transmits the go-ahead signal, and the tape reader is turned on once again at the selected-to-send station. If the station has additional messages to transmit, the reader continues to advance the tape until the controller detects and transmits the SOH character denoting the beginning of a new message. ADF will restart the tape reader and repeat the pick-up process described above. If no additional messages are available, ETX on the tape is followed by EOT. The EOT is transmitted by the controller and the station becomes unselected as a sender and returns to the idle state. If the controller's EOT counter indicates zero, the controller stops the tape reader, otherwise the tape is permitted to advance until the next SOH is detected. SOH stops the reader and cycles the controller logic to the traffic-available state.

3.2.2.2 *Full-duplex.* On a full-duplex line, after transmitting the originating time, date, and message number to the selected-to-send station, ADF transmits control character DC2 (Device Control 2). The controller detects DC2, starts the tape reader, and restores the receive portion of the line to the receive-only teletypewriter. Since intraline delivery is not possible on full-duplex lines, the controller, in contrast to half-duplex operation, does not stop the transmitter until both the heading and the message text are transmitted, i.e., until the controller detects ETX from the tape. Local copy is provided on the typing unit of the sending teletypewriter. Except for the different go-ahead control character, DC2 instead of STX, the remainder of the full-duplex pick-up sequence is identical to that for half-duplex. After message pick-up has been completed ADF polls a full-duplex line in order to determine if traffic has become available during the pick-up process.

3.2.3 *Hold Feature*

In the process of sending many messages during a single transmission it may be desirable to transmit a message of higher precedence

from a separate piece of prepared tape. The hold feature allows the station attendant to remove the in-progress tape and introduce a "torn-tape" message without affecting the station's status as a selected sender. When the HOLD key on tbe attendant unit is operated, the controller inhibits ADF from restarting the tape reader after it has been stopped following detection of ETX. When the tape reader stops, the HOLD key lamp lights indicating that the original tape may be removed and the new tape inserted. Tbe station remains selected as a sender and the station attendant may restart the tape reader. To reintroduce the original tape, the bold process is repeated.

3.2.4 *Emergency Stop*

During transmission from the station, ADF checks for invalid address information and errors in message format. If a violation is detected, ADF initiates an emergency stop sequence. This procedure stops the station's tape reader and activates an alarm; ADF then delivers a service message to the offending station indicating the nature of the error.

ADF interrupts a balf-duplex sender by transmitting a break signal, i.e., several character intervals of steady spacing followed by a sequence of control characters that unselects the station as a sender, activates an alarm and unblinds the station receiver. After delivery of the service message ADF restores the station to the idle state.

In the case of a full-duplex station, ADF transmits a sequence of control characters that interrupts the sending station and blinds all called-in receive stations on the line. After sending the service message, which is copied by the typing unit of the sending teletypewriter, ADF sends a sequence that unselects the sending station and unblinds any selected receivers and then resumes delivery of the message to the selected receivers.

3.3 *Receiving at the Station*

3.3.1 *Call-In and Message Delivery*

If ADF has a station marked ready to receive as a result of the polling cycle, the station is eligible for selection as a receiver, an operation referred to as "call-in." To select a station ADF transmits a two-character sequence, ENQ followed by the station's unique call-enquiry code. This sequence is identical to the sequence used to select a station as a sender but is distinguishable since the controller is not in the polling state.

As mentioned previously, full-duplex stations are arranged to send and receive traffic simultaneously. During the course of receiving a message, the station controller must generate and transmit control characters in response to interrogation by ADF. When the station is in the process of sending, the control character ENQ interrupts the transmission permitting the receive portion of the controller to access the sending logic in order to generate and transmit the necessary responses.

ENQ followed by the station's call-enquiry code elicits a two-character response from the controller, the station-identity code followed by ACK or NAK. The station-identity code is used by ADF to verify that the response originated from the station that was called. NAK indicates that tbe station is not ready to receive for reasons previously described in Section 3.2.1. Further attempts to call-in a station responding with NAK will not be made until the station is found to be ready during a subsequent polling cycle. When the controller generates the NAK response, a lamp (CALL) lights on the attendant unit of the receive teletypewriter to alert the station attendant to the call-in attempt.

The station response ACK, i.e., ready to receive, automatically selects the station as a receiver, causing a lamp (REC) on the attendant unit of the receive teletypewriter to light. ADF may now transmit any per-station heading information such as a receive-message number. If additional stations on the same line are designated as recipients of the message, ADF transmits ENQ followed by the call-enquiry code of the second station. ENQ blinds the receiver of the first station ensuring private delivery of per-station information to the second station. To call in additional stations the process described above is repeated. When call-in has been completed, ADF transmits the sequence ENQ DC2 and unblinds all called-in stations. DC2 also reactivates any sending full-duplex station that was interrupted when call-in was initiated. ADF now transmits the text of the message followed by the control character ETX.

3.3.2 *Roll-Call*

As stated previously, ADF unblinds all selected station receivers prior to message delivery by transmitting the sequence ENQ DC2. DC2 also enables that part of the controller logic that monitors "proper" reception of the message. This logic state is referred to as "roll-call." Specifically, any one of the following occurrences indicate improper reception:

(*i*) A character received by the controller did not reach the receiving teletypewriter.

(*ii*) A receiving teletypewriter that utilizes paper forms ran out of forms before the end of the message.

(*iii*) The control character ETX was not detected or was received with a parity error.

After transmitting ETX, ADF interrogates each station in turn using the sequence ENQ followed by the station's call-enquiry code which, since the controller is in the roll-call state, is interpreted as the beginning of the roll-call sequence rather than either a call-in or select-to-send sequence. The controller generates and transmits a 2-character response, the station-identity code followed by either CAN or NAK. CAN indicates proper reception; NAK indicates improper reception and activates an alarm on the attendant unit. After all stations are roll-called, ADF transmits EOT which restores all stations to the idle state. In the event a station responds NAK to roll-call, ADF makes another attempt to deliver the message. If the second attempt is not successful ADF passes the message to a network control station for appropriate action.[4] On full-duplex lines, DC2 is sent after EOT to reactivate an interrupted sending station, if any.

3.3.3 *Receive Message Abort*

This feature allows ADF to interrupt message delivery to a station and activate a station alarm if an irregularity is detected in the message or if some other system anomaly occurs.

On a full-duplex line ADF transmits a sequence of control characters that interrupts any selected sender and activates an alarm at selected receive stations. ADF then transmits a service message indicating the reason for the delivery interruption, then idles all selected receive stations and restarts the interrupted sending station.

On half-duplex lines ADF sends a sequence of control characters that activates an alarm at the selected receive station and in the case of an intraline delivery, also interrupts the tape reader at the sending station and activates an alarm (see Section 3.2.4). After sending the service message, ADF restores the sending station, if any, and all selected receive stations to idle.

3.4 *Controller Operation*

3.4.1 *Character Processing*

All data exchanged between the station teletypewriter and the line

is monitored, temporarily stored, and then regenerated hy the station controller. The character-processing circuits perform the required timing, storage, control character detection and response generation. The functional form of this circuit for the half-duplex controller is shown in Fig. 14. To facilitate simultaneous reception and transmission, the full-duplex controller contains two character-processing circuits.

Each character, from either the teletypewriter tape reader or the receive-data lead of the data set, initiates a new timing cycle and is stored in a 10-stage magnetic core shift register. Special windings threaded through the eores of the shift register permit detection and generation of the necessary control characters. During message transmission, characters are read into the shift register and applied to the line simultaneously. However, the shift register is in series with the received data stream; therefore, a character received from the line is stored in the register until shifted out hy the timing cycle initiated by the following character. By introducing a delay of one character interval during reception, sufficient time is gained to permit the use of gating cireuits to prevent sequenee-control characters transmitted hy ADF from reaching the station teletypewriter.

Pulses from the character-detection circuits sequence the controller's state logic through the various operational modes. Status signals from the station teletypewriter and attendant unit are monitored hy the state logic and exercise control over the writing and gating circuits.

3.4.1.1 *Timing.* Three timing signals are necessary for charaeter processing. One, derived hy the eharacter timer, defines the eharacter interval; the seeond, provided hy the bit clock, defines the element or hit* interval. The third will he discussed in Section 3.4.1.2.

In the idle state, the input-data lead is marking. A mark-to-space transition, denoting the beginning of a eharacter, initiates the timing cycle hy starting the character timer, the hit clock, and the clock-guard timer. The output of the bit-clock circuit is a square wave; the period of one cycle of the square wave is equivalent to a hit interval. The bit clock is permitted to run for ten cycles before heing squelched by the character timer. Data sampling and shifting operations are timed hy the hit clock.

The shift register is divided into two parallel 10-stage information stores. One stores marking hits and the other stores spaeing hits. A

* In the strict sense, not all the elements of the teletypewriter character may be defined as "bits". For convenience, however, the term will be used in this discussion.

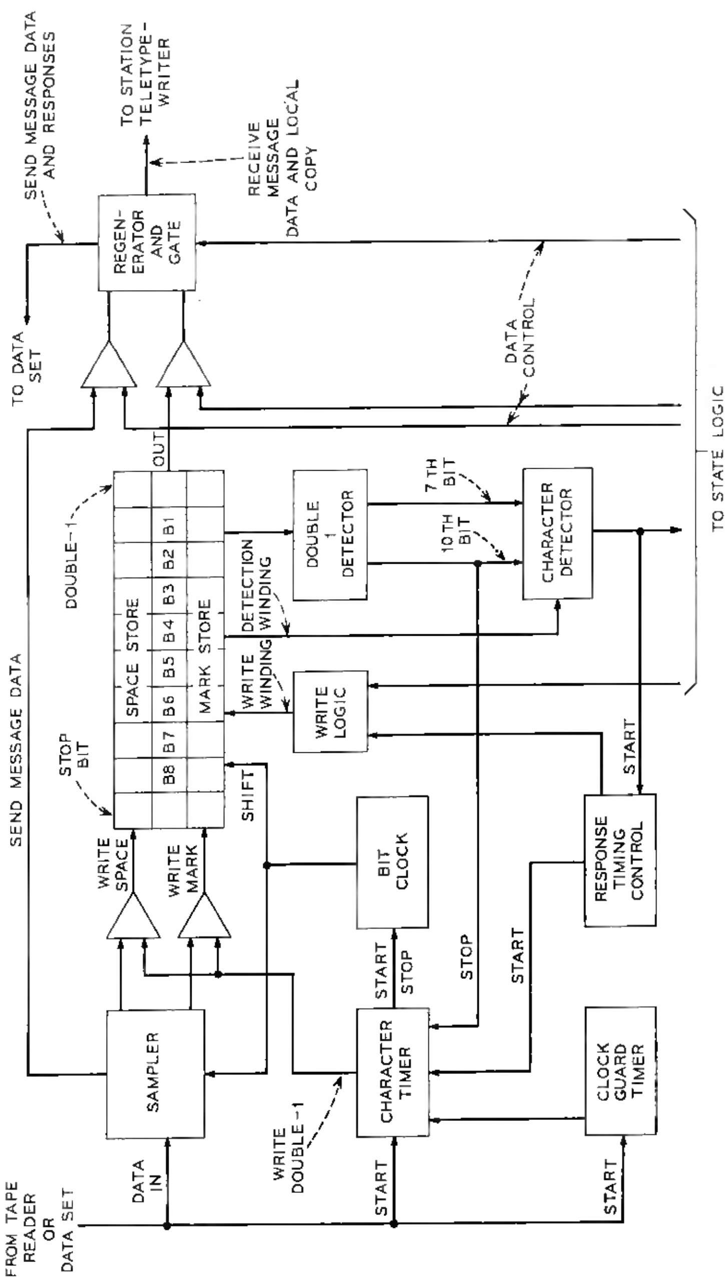

Fig. 14—Functional form of half-duplex character processing circuit.

logical 1 is entered into the appropriate store as each bit following the start bit is sampled. Coincident with the start bit, however, a "double-1" is entered into the register; i.e., a 1 is entered into both the mark and space stores. As each of the remaining nine bits (seven-bit ASCII character, parity bit, and one-stop bit) is sampled and entered into the register, the double-1 propogates through the register and is detected as it enters the tenth position, coincident with the center of tenth-timing cycle. When the double-1 is detected, a pulse is fed back to the character timer and terminates the timing cycle. The clock guard timer, which is reset at the beginning of each timing cycle, prevents the bit clock from free-running in the unlikely event a double-1 pulse is not detected or is mutilated.

The possibility exists that the bit clock may be falsely started, by a hit due to line noise for example. The write and detect double-1 sequence still occurs and the normal timing interval is maintained. Unless certain repeated characters are received causing the timing circuit to synchronize on some mark-to-space transition other than the normal-start transition, synchronization is quickly regained. In order to reduce the number of incorrect characters that are printed or punched while the receiver is recovering synchronization, the received data is sampled at the end of the timing interval, coincident with what would normally be a marking stop bit. If the sample is found to be spacing, the received character is changed to an "underline" (_) character by the write circuit before it is passed to the teletypewriter. In addition, characters received from the line are also checked for parity. Those having incorrect parity are also changed to an underline.

3.4.1.2 *Character Detection and Generation.* A separate wire, which acts as a detection winding, is threaded through the cores of the shift register for each character to be detected. Each wire is threaded in a unique manner, governed by the mark-space bit pattern of the character to be detected. Except for the SOH, ETX and STX windings, the wires are arranged so that the characters are detected as the stop pulse is written into the shift register. As described in Sections 3.2.1 and 3.2.2, the controller is required to stop the station's tape reader when message-format characters are detected from the tape; these stop characters are SOH, ETX and, in the case of half-duplex operation, STX. The station's tape reader must be stopped before reading the character following the stop character. To gain time, therefore, the windings for the stop characters are arranged to permit detection as the seventh ASCII bit is written into the register, without regard for the parity bit. The presence of a character that agrees with the

winding pattern of a detection winding is indicated by a negative pulse on the winding output, provided it occurs at the appropriate point in the timing cycle. Other characters yield positive pulses. In order to sample the detection windings of the stop characters, a third timing signal is derived by an additional double-1 detector which is arranged to detect the double-1 coincident with the center of the seventh ASCII bit; the other detection windings are sampled by the same double-1 pulse employed to terminate the timing cycle. Pulses from the character-detection circuits are applied to the controller's state logic to initiate automatic sequencing of the various operational modes.

When the state logic is conditioned to the appropriate mode, the detection of certain control characters will initiate a response sequence. The response-timing control circuit is triggered by a signal from the state logic; the state logic also indicates whether a 1- or 2-character response timing cycle is required.

A separate write winding is threaded through the shift register cores for each of the characters to be generated. A current driver is associated with each write winding and the desired character is written into the register by applying a narrow current pulse to the appropriate winding. To do this, the response-timing control circuit applies a pulse to the write logic. The pulse is gated under control of the state logic to the appropriate current driver and the character is written into the shift register. After a suitable delay, the response-timing control circuit applies a pulse to the character timer and a timing sequence is initiated. The character residing in the register is shifted out, passed to the data set and transmitted. If the state logic indicates that a second character is required, the response timing control is enabled by the character timer at the end of the timing cycle and the write and shift process is repeated.

3.4.2 *Alarms*

A number of alarm conditions are detected by the controller. Lamps on the attendant unit indicate the nature of the alarm condition; an audible alarm is also provided by a loudspeaker housed in the attendant unit. A list of the alarms and their meaning is given below.

(*i*) TAPE: This alarm monitors the status of tape in the teletypewriter tape reader while the station is selected as a sender. The alarm is activated if the tape reader runs out of tape or if the tape becomes taut. The latter condition is likely to occur when tape is fed directly into the tape reader from the punch with insufficient

slack. The alarm also occurs if the tape is removed from the reader or if the switch on the reader is moved from the RUN position. This alarm circuit is disabled when the hold feature described in Section 3.2.3 is in effect.

(*ii*) EMERGENCY STOP: Tbis alarm occurs when ADF initiates the emergency-stop sequence described in Section 3.2.4.

(*iii*) PAPER LOW: For teletypewriters that use paper on rolls, the alarm condition is indicated when the diameter of the paper supply roll is reduced to a prescribed dimension. In the case of teletypewriters that use paper forms, the alarm is not given until forms are depleted.

(*iv*) TAPE LOW: This alarm is provided to indicate a low tape-supply condition when the station is equipped with an ROTR.

(*v*) MESSACE RECEPTION: A message-reception alarm is given whenever a station responds NAK to roll-call indicating "improper" receipt of a message. The conditions that elicit this response are described in Section 3.3.2. In addition, this alarm is triggered at a selected receive station if ADF interrupts message delivery in order to transmit a service message.

(*vi*) ERROR: This alarm occurs if a parity error is detected or if the normally marking stop element is found to be spacing in a character received from the line. In addition to generating the alarm, the controller changes the affected character to an underline character with incorrect parity before it is gated to the teletypewriter.

The alarm lamps are located under translucent nonlocking keys on the attendant unit; by depressing the lighted key the alarm lamp and audible tone may be turned off. Tbe PAPER LOW and TAPE LOW alarms, however, cannot be canceled until the paper or tape supply is replenished. A separate locking key is provided to allow the attendant to disable the audible alarm.

3.5 *Maintenance Features*

3.5.1 *Local Tests*

Model 33, 35 and 37 ASR teletypewriters are equipped with a mode switch. Using this switch the teletypwriter may be switched off-line, isolating the machine from the station controller. When off-line, the typing unit and punch operate from either the keyboard or tape reader allowing the operator to check basic machine functions. When the station is polled while in the off-line mode, the full-duplex controller will respond "no traffic available;" half-duplex stations equipped

with an ASR teletypewriter will, in addition, respond "not ready to receive." If an attempt is made to select a half-duplex station as a receiver while the ASR is off-line, the CALL lamp on tbe attendant unit will light, alerting the station attendant to the call-in attempt.

3.5.2 *Remote Tests*

When the station is equipped witb an ac data set, a switch (MTCE) located on the controller may be used to interconnect the send and receive data leads of the data set. Thus, with the remainder of the controller and the station teletypewriter isolated, tests of the transmission facility and data set may be performed from a remote test center.

Remote tests of many controller functions may be performed using an automatic loopback feature provided by the controller. If the controller is equipped with the ac data set, it may be conditioned to the automatic loopback mode from a remote test facility by transmitting a prescribed sequence of control characters. The sequence forces the station to the "ready" mode and permits tbe station to be selected as a receiver using the normal call-in process. The controller's state logic now causes all data that would normally be passed from the data regeneration and gating circuits to the station teletypewriter to be looped back to the data set and transmitted to the line. Since much of the controller logic is included in the loopback path, many controller functions may be verified merely by monitoring the returned data at the test facility. For example, the ability of the controller to detect control characters used to blind and unblind the station receiver can easily be tested since the printer control logic will control the looped-back data. The obvious advantage of the automatic loopback feature is that maintenance personnel need not be dispatched to the station; nor do any switches have to be operated by the station attendant. By transmitting EOT the test facility returns the station to the idle state.

IV. CONTROLLER APPARATUS

The station controller consists of a wired nest equipped with a power supply and 13 printed circuit boards, and measures 15.5 inches long by 7.5 inches wide by 6 inches higb (see Fig. 15). Different brackets are available to permit installation of the controller within various types of teletypewriters. Cords are used to interconnect tbe controller to the attendant unit and teletypewriter.

The data set is contained on one of the printed circuit boards; the other boards provide all of tbe controller logic. Discrete components

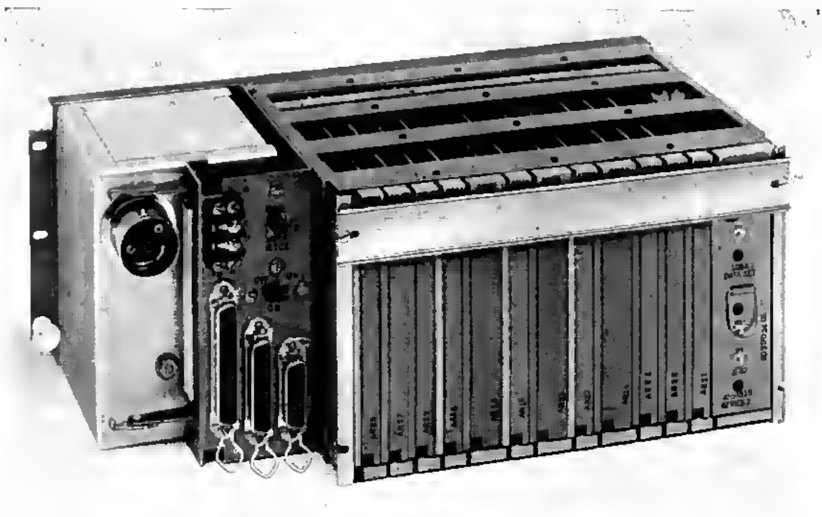

Fig. 15—Full-duplex station controller equipped with data set 108 type.

are used; each logic board contains, on the average, 13 capacitors, 12 diodes, 95 resistors and 26 switching transistors. The controllers may be equipped with either of two clock circuit boards, one for 100-words-per-minute operation, the other for 150-words-per-minute operation.

The power supply converts standard 117 volts, 60 Hz ac power to +24, +12 and −12 volts dc for use in the controller. The controller dissipates 50 watts of power making forced ventilation within the teletypewriter pedestal unnecessary in environments at normal room temperature.

The attendant unit for a half-duplex send-receive station is shown in Fig. 16. The loud speaker for the audible alarm is clearly visible. The attendant unit mounts under a cutout of the Model 33 and 35 teletypewriter cover as shown in Figs. 3 and 6. In the case of Model 37 teletypewriters, the attendant unit is installed in a vertical door panel as shown in Fig. 8.

V. CONCLUSION

The marriage of the electronic controller and the teletypewriter has been successful. Since system cutover on February 3, 1969, the stations have operated with a high degree of reliability.[7] This performance, coupled with the ability of ADF to frequently check the

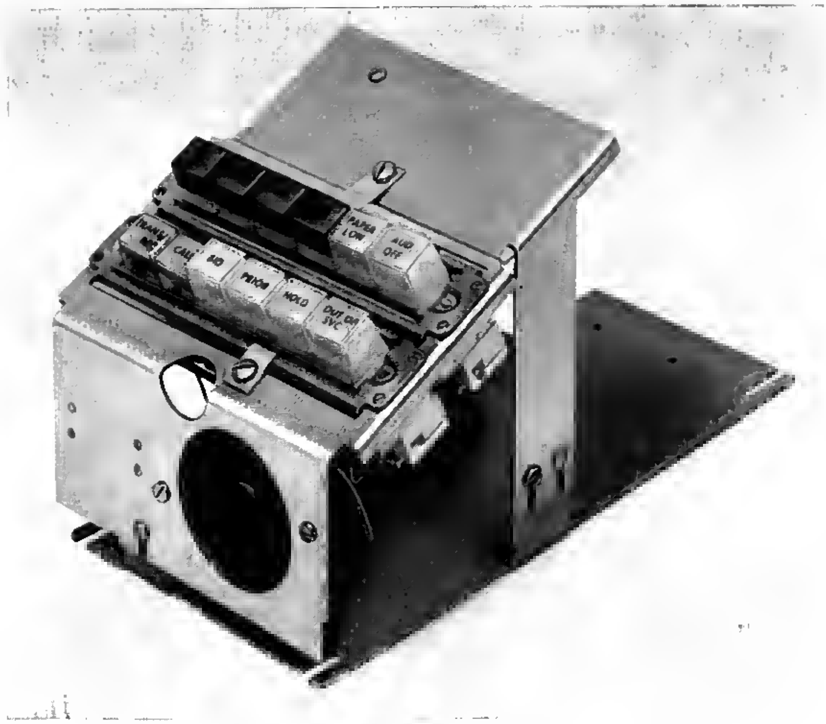

Fig. 16—Attendant unit for half-duplex send-receive station.

status of all stations and the inherent reliability of the private line telegraph network, has contributed significantly to the users' confidence in the No. 1 ESS ADF system.

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